Two Keys for Appraising Forest Fire Fuels

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Introduction

This is an attempt to characterize forest fire fuels[1] in a new way. The immediate purpose is to provide means for recognizing and tentatively evaluating, in the field, the fire spread potential and the crowning potential of fuels on the basis of readily observed characteristics without need for prior technical knowledge of vegetation or experience with fire. The medium employed is the dichotomous key, familiar to natural scientists; this is supplemented by a vocabulary of newly defined terms for describing fuel characteristics. The ultimate goal is to establish the framework for a permanent, universal fuel appraisal system.

Forest fire fuels comprise an infinitely varying conglomeration of living and dead vegetation. Numerous existing systems characterize this material, or some parts of it, in terms of taxonomic identity, ecological significance, and economic value. Each type of characterization implies something about the vegetation as fuel, but none provides a complete fuel evaluation. Therefore, foresters have devised their own schemes for evaluating, or "classifying," fuels in terms that have meaning for fire control.

Fuel classification in the United States is based on a system developed 30-odd years ago before any information existed on specific relations between measured fuel characteristics and fire behavior (Hornby 1936).[2] The unit of measurement is fuel type, a largely impressionistic integration of vegetation and site factors into dual ratings for expected rate of fire spread ("rate of spread") and difficulty of effecting control ("resistance to control"). Regional variations of the system provide photographic manuals for identifying fuel types, and most give numerical values for rate of spread and resistance to control.[3] The value scales are regional, without a common base.

Long use attests to the great practical value of the present fuel classification system in fire control planning and, to a lesser degree, in fire suppression. However, increasing dissatisfaction suggests that the system's longevity owes much to the difficulty of developing a suitable replacement. Departures from the general scheme thus far have dealt with rather narrow, usually local or regional problems, e.g., the first known fuel key, relating "blowup potential" to total weight (Wendel, Storey, and Byram 1962). To be a real improvement, a comprehensive new approach must (1) be based on objective measurement of specific fuel characteristics, (2) be much more flexible and versatile than the present system, and (3) use a universal rating scale.

Keys such as those commonly used to identify natural substances and organisms afford a versatile and flexible approach to fuel characterization. In principle, such keys distinguish between significant conditions by means of progressive subdivision, using as the criterion at each division point a characteristic that one entity possesses and all others do not. Thus the job of distinguishing between two complex fuels is reduced to a series of rather minor decisions, each of which can be made on the basis of objective observation or measurement. If the right basic attributes are used for characterization, critical levels can be redefined, outputs can be recalculated, combinations can be added, and keys can be combined or separated to incorporate new knowledge without invalidating the system.

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[1] *Includes grassland, brush, woodland, forest, and tundra fuels.*

[2] *Names and dates in parentheses refer to Literature Cited, page 23.*

[3] *All regions use at least four relative levels: "Low," "Medium" or "Moderate," "High," and "Extreme." Forest Service Regions 1 and 4 add a "Flash" rate-of-spread category for grass and some other fine fuels. Fuel types are designated as "Low-Low (L-L)," "High-Extreme (H-E)," etc., with rate of spread always the first element.*

Fuel Terminology

An effective descriptive system must have a vocabulary of precisely defined terms. In the case of fuels, the terms must describe size, quantity, and arrangement of particles, the intrinsic characteristics that govern fire behavior and impede fire suppression (Fons 1946, Fahnestock 1960, Anderson et al. 1964, Rothermel and Anderson 1966). The available terminology for characterizing fuels is notably meager, and the same words are commonly used to mean entirely different things; e.g., "heavy" for either coarse or abundant, and "light" for either fine or sparse. "Heavy" and "light" are used also to describe weather phenomena, strength of attack, and other factors in fire control; consequently, their meanings in each context often are vague to the point of uselessness.

The proposed keys use criteria of size, quantity, and arrangement that can be defined by rather simple observations. The suggested terminology, which is completely new, defines these attributes in quantitative terms to the extent currently possible. Some dimensions are based on fire behavior theory and drying regimes to be used in the National Fire-Danger Rating System, but many, at this stage, represent mainly experienced judgment.

The terms are grouped into four categories: size and shape of particles, compactness, vertical position, and horizontal continuity;[4] i.e., size and three aspects of arrangement. Figures 1-4 illustrate different combinations of these characteristics. These attributes can be expressed in terms of simple, easily estimated dimensions and distances. However, quantity, usually expressed as weight per unit of land area, is extremely difficult to estimate. Therefore, levels of quantity are not defined specifically for use in the keys but are inferred as functions of size and arrangement. Certain other variables and interactions are ignored for the present because their effects on fire behavior are understood poorly, if at all; these include density (specific gravity), chemical composition, and the intermixing of particles of different sizes and moisture contents (e.g., green and dead). As knowledge improves, correction, refinement, addition, and deletion should be possible without reducing the overall usefulness of the terminology.

[4] *Terms for horizontal continuity are used to interpret areal groupings of key readouts, not in the keys themselves.*

Size and Shape of Particles

Tinder — low-density, commonly amorphous solids or aggregates of particles; includes duff, peat, rotten wood.

Fine — thin (<one-thirty-second inch) or of small diameter (<one-eighth inch); equivalent to 1-hour-timelag category used in fire-danger rating (cf. USDA Forest Service 1956); includes leaves, grass, fine twigs, moss.

Small — minimum dimension, one-eighth inch; maximum cross-sectional area, 0.2 square inch (equivalent to ½-inch-diameter cylinder); approximately equivalent to 10-hour-timelag category used in fire-danger rating; includes woody stems, branches, and slivers, and thin sheets of bark.

Medium — minimum dimension, one-half inch; maximum cross-sectional area, 7 square inches (equivalent to 3-inch cylinder); approximately equivalent to 100-hour-timelag category used in fire-danger rating; includes branches, stems, and slivers, and bark.

Coarse — minimum dimension, 3 inches; maximum cross-sectional area, 113 square inches (equivalent to 12-inch cylinder); timelag, >100 hours; includes saplings, poles, logs and chunks, slivers, and bark.

Big — minimum dimension, 12 inches; timelag much more than 100 hours; includes all material not covered above.

Compactness

Fuels in the surface layer:

Compact — particles in close contact with each other over much of their surfaces; voids in fuel bed almost imperceptible — examples are beds of conifer needles ≤1½ inches long, matted hardwood leaves, and other compacted fine fuels; applies mainly to fine size class.[5]

Thatched — particles oriented horizontally in close juxtaposition, touching each other at many points; voids perceptible in fuel bed but less conspicuous than fuel particles; examples are beds of conifer needles 1½ to 6 inches long, unmatted small hardwood leaves (willow, birch, black gum, beech, elm), twigs; also longer needles and larger leaves, after compaction by snow or winter rain or when quantity is too small for next category; applies to fine and small size classes.

Jumbled — particles variously oriented in close association, touching and supporting each other at several to many points; voids in fuel bed conspicuous, having volume many times greater than fuel particles; examples are conifer needles >6 inches long, unmatted large hardwood leaves, and concentrations of woody fuel; applies to fuels of all sizes.

Fluffy — particles generally self-supporting, oriented approximately in normal growing position; fuel bed has appearance of space with suspended particles; examples are grass, ferns, lichens, moss; applies to fine size class only.

Fuels above the surface layer:

Dense — particles mostly <3 inches apart within each integral group (spray, branch); groups no farther apart than 12 inches horizontally and 18 inches vertically; applies to only fine and, occasionally, small fuels. Examples are logging slash with foliage attached and much-branching, small-leaved brush.

Open — particles 3 to 6 inches apart within groups; groups 12 to 18 inches apart horizontally and 1½ to 3 feet vertically. Examples are logging slash of fine-twigged species after foliage falls and less-branched brush.

Fuels in all positions:

Sparse — too little fuel present to produce any of the conditions defined above.

[5] *"Tinder" fuels may be considered compact by definition.*

Vertical Position

Subsurface — beneath all other fuel with no exposure to the atmosphere. Consists mainly of partially decomposed material in the tinder and fine size classes; sound larger components may be imbedded. May be absent.

Surface — stratum not more than 1 foot deep resting on mineral soil or subsurface fuel, with its top exposed to the atmosphere. Includes litter, larger debris, and associated low-growing vegetation.

Low — lowest, essentially homogeneous, completely aerial stratum; mean depth (height) usually <6 feet.

Intermediate — homogeneous stratum immediately above low stratum and usually reaching ≤ 15 to 20 feet in average height.

Subcanopy — stratum between intermediate and canopy; considered to be absent if base of canopy is within 10 feet of intermediate or lower stratum.

Canopy — stratum containing crowns of tallest vegetation (living and/or dead) >20 feet high.

Ladder — providing vertical continuity between strata, but horizontal continuity too poor to be considered a fuel bed.

Horizontal Continuity

Uniform — essentially the same fuel bed over entire area;[6] breaks and patches of different fuel few (as defined by key), generally narrower than (1) the expanse of typical fuel between them and (2) twice the maximum height of available fine fuels; breaks (without fuel, as defined above aggregating less than 25 percent of area.

Mixed — containing up to 50 percent of different fuel distributed in patches no wider than twice the average height of finest fuels in the taller fuel type.

Interspersed — containing up to 50 percent of a different fuel or fuels distributed in patches wider than twice the average height of finest fuels in the taller fuel type but not large enought to be rated or mapped separately.

Broken — 25 to 75 percent of the area occupied by breaks wider than the expanse of fuel between them and wider than twice the maximum height of finest fuels, but not wider than five times the maximum height of finest fuels.

Interrupted — containing one or more breaks wider than five times the maximum height of fine fuels and long enough to be of significant assistance in fire suppression.

[6] *Size or limits of area to be defined by map or description for each specific situation.*

a. b. c. d. e. f.

Figure 1. — Fine surface fuels.

a. Fluffy — cheatgrass (*Bromus tectorum* L.), Montana.
b. Jumbled to fluffy — longleaf pine litter (*Pinus palustris* L.), Louisiana.
c. Jumbled — hardwood leaves, California.
d. Thatched — loblolly pine (*P. taeda* L.), North Carolina.
e. Compact — western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Washington.
f. Tinder — rotten wood, Washington.

Figure 2. — Larger fuels (all Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock, Washington).

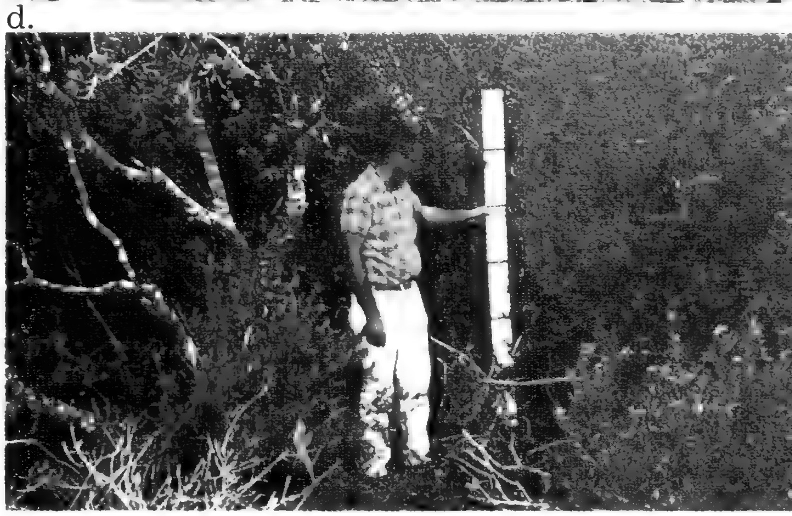
a. Small b. Medium c. Coarse d. Big

a.

b.

c.

d.



f.

e.

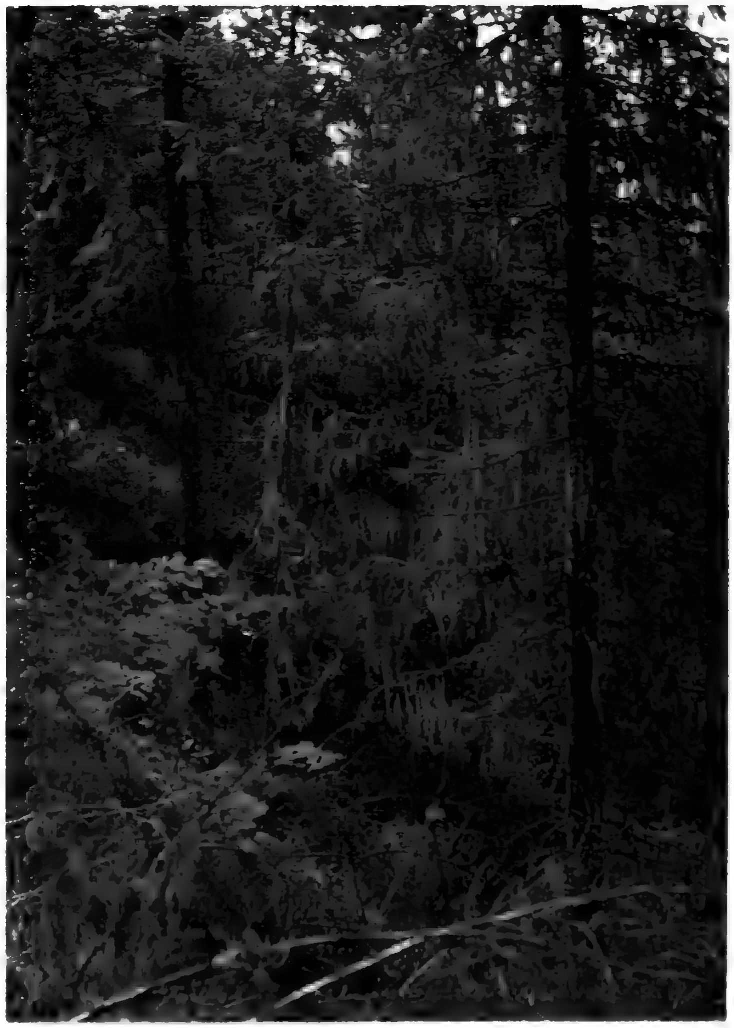
Figure 3. — Various conformations of low and intermediate fuels.

a. Low: fine and small, dense to open; over surface: fine — old chamise (*Adenostoma fasciculatum* H. & A.), California.
b. Low and intermediate: fine and small, dense; over surface: fine sparse — chamise, California.
c. Low: fine, dense; over surface: fine, jumbled — lambkill (sheep laurel) (*Kalmia angustifolia* L.), New Jersey.
d. Low and intermediate: fine to coarse, dense to open — lodgepole pine slash (*Pinus contorta* Dougl.), Oregon.
e. Low and intermediate: fine and small, dense — canebrake (*Arundinaria* spp.), North Carolina.
f. Intermediate: fine, dense; over surface: fine, thatched or compact — swamp cyrilla or titi (*Cyrilla racemiflora* L.), Florida.

a.

b.

c.



d.

Figure 4. — Ladder fuels.

a. Loose bark on redshank chamise (*Adenostoma sparsifolium* Torr.), California.
b. Draped pine needles, California.
c. Scaly bark, dead twigs, and lichens on black spruce (*Picea mariana* (Mill.) B.S.P.), Alaska.
d. Beard lichens (*Usnea* sp.), Washington.

Mechanics of the Keys

Both keys — rate of spread and crowning potential — employ the basic rationale and mechanics of the dichotomous key. The user proceeds, step by step, through a series of yes/no choices, to a combination of conditions that defines the fuel in question. Procedure for using the keys is:

1. Enter key with "A."

2. If condition defined by "A" fits fuel under observation, proceed to "B" as directed.

3. If "A" does not fit, proceed to "AA" and on to "AAA" if necessary.

4. Proceed through the alphabet in the same manner to the key readout that has a type number (XX) and a rating rather than an instruction to proceed further.

The fuel keys are not strictly dichotomous in form, since some steps require choice among three or four mutually exclusive conditions. However, these situations are merely shortcuts used to reduce the number of steps that would be required to preserve pure dichotomy.

A second minor departure from the typical eliminative process is that some portions of the fuel keys are accumulative. Therefore degree or progress through a key does not represent relative rating of the fuel.

Both keys have been repeated on tearsheets at the end of the report.

Rate-of-Spread Key

Key No. 1 defines 36 distinct combinations of fuel characteristics in terms of potential rate of fire spread. Fine fuels are considered to control spread so long as they are not characterized as "sparse" or absent. Fire spread is assumed to be entirely through the fuel bed itself, governed by thermal radiation, convection, and conduction within the bed. No basis exists for estimating the expected number and characteristics of firebrands for mass transport, and consequent spread by spotting, that any fuel will produce.

The key does not take into consideration the influences of topography or weather, either synoptic or as modified by terrain and vegetation. These are considered external factors whose effects can be combined mathematically with the effect of fuel characteristics to calculate expected rate of spread in any given situation. The basis for estimating effects of external factors is available in several forms — publications (e.g., Barrows 1951, Geiger 1966, USDA Forest Service 1964), the proceedings of national fire behavior courses, and regional fire control handbooks.

A recognized weakness of the key is lack of any distinction between living and dead vegetation. Dead material is everywhere the basic fuel whose flammability depends only on weather. However, nearly every vegetative region has species that burn while living as a result of basic chemical composition, physiological changes, and drought (Philpot 1968, 1969). In some regions, e.g., southern California, living vegetation is the most important fuel. To use the key in such areas, one must recognize, on the basis of local knowledge, and consider as available fuel the living vegetation that is currently flammable. Nonflammable living vegetation is regarded as so much empty space, since its effect on fire spread is not known.

Readouts of the key are relative ratings on a scale of 100 conditioned by the following assumptions:

1. No wind
2. Other external factors equal (aspect, slope, stand density, etc.)
3. No change in relative rate of spread with change in fire danger[7]
4. Finest fuel present in appreciable quantity controls spread, although loading of coarser fuel may be greater.

Assumption 3 is not strictly true, but it provides a premise from which to qualify and take exception (see "Interpretation of Ratings").

As the basis for ratings, linear rates of spread for a wide range of essentially homogeneous surface fuels were calculated at the Northern Forest Fire Laboratory, by means of a mathematical model[8] (table 1). The mean rate of spread for two common grass types was given the top rating of 100; field experience strongly suggested that the actual difference between broomsedge (*Andropogon*

[7] *Used loosely here to mean the summation of effects of all weather factors that affect fire behavior.*

[8] *Rothermel, R. C. The effects of fuels on fire intensity and rate of spread. (Unpublished paper presented at the Forest Fuels Work Conference, Northern Forest Fire Laboratory, Missoula, Mont., March 3-6, 1969.)*

Table 1. — Assumed inputs and calculated rates of spread for fine, homogeneous fuels

Fuel, by compactness class	Heat value	Mineral content		Density	Surface/ vol. ratio	Load- ing	Depth	Fire spread	
		Total	Effect					Rate	Rating
	B.t.u./lb.	Percent dry wt.		Lb./ft.^{3}	Ft.^{2}/ft.^{3}	Lb./ft.^{2}	Ft.	Ft./min.	
Fluffy:									
Broomsedge	7,350	5.27	1.04	21.2	2,440	0.15	3.0	9.40	—
Cheatgrass	7,350	5.27	1.04	21.2	4,390	.02	1.0	5.58	—
Mean for grasses								7.49	100
Jumbled:									
Longleaf pine litter	8,744	3.87	1.55	31.8	1,750	.14	.40	1.38	18
do.	8,744	3.87	1.55	31.8	1,750	.07	.12	.43	6
Thatched:									
Ponderosa pine litter	8,744	3.87	1.55	31.8	1,750	.14	.10	.30	4
do.	8,744	3.87	1.55	31.8	1,750	.07	.07	.23	3
Western white pine litter	8,456	3.34	2.54	33.5	2,800	.14	.09	.29	4
do.	8,456	3.34	2.55	33.5	2,800	.07	.05	.17	2
Compact:									
Douglas-fir litter	8,500	4.09	2.45	32.0	2,160	.14	.04	.05	1
do.	8,500	4.09	2.45	32.0	2,160	.07	.02	.02	<1

virginicus L.) and cheatgrass is much less than the calculated difference, possibly nonexistent. Maximum rate of spread in each other category was divided by the mean for grass to obtain the other relative ratings. Maxima were used to avoid underestimation; the assumed inputs on which they were based were not absolute maxima.

Ratings for the more complex fuels were extrapolated from the few basic determinations on the basis of judgment guided by the size and spacing relations developed by Fons (1946) and a few calculations with a rate-of-spread model for heterogeneous fuels. The calculations indicated potential spread in heavy logging slash and chaparral approximating that in grass and suggested about a 90-percent reduction in slash when the needles fall off.

Sampling units for rating fuels with the key must be randomly or mechanically selected small plots. One milacre appears to be a reasonable, all-purpose size. A larger plot usually contains so much variation that giving it a single rating is impossible; a much smaller plot too often is virtually devoid of fuel or contains only surface fuel. Considerable variation may occur even on a single milacre; therefore, the practice should be to key out the fuel that gives the highest rating and from which fire could spread outside the plot. This judgment admittedly is somewhat subjective, but anybody who has had a bonfire can be reasonably sure of judging correctly on such small plots. More use of the keys will be needed to determine the number of observations needed. Ten plots appear to give a reasonable mean rate-of-spread rating for most areas; more are needed in patchy fuels.

Key No. 1: Rate of Spread

	Rating
A. Fuel essentially confined to surface layer — B	
B. Fine fuel present, not sparse — C	
C. Fine fuel fluffy (1) (fig. 1a, b)	100
CC. Fine fuel jumbled (2) (fig. 1b, c)	18
CCC. Fine fuel thatched — D	
D. Small fuel jumbled (3)	10
DD. Small fuel, if present, not jumbled (4) (fig. 1d)	5
CCCC. Fine fuel compact — E	
E. Small fuel jumbled (5) (fig. 2a)	5
EE. Small fuel thatched (6)	3
EEE. Small fuel sparse or absent — F	
F. Medium fuel jumbled (7) (fig. 2b)	3
FF. Medium fuel not jumbled (8) (fig. 1e)	1
BB. Fine fuel sparse or absent — G	
G. Small fuel jumbled or thatched (9)	3
GG. Small fuel sparse or absent — H	
H. Medium fuel jumbled (10)	2
HH. Medium fuel not jumbled — I	
I. Larger fuel jumbled (11)	1
II. Larger fuel not jumbled (12)	<1
AA. Fuel available in low and/or intermediate layers — J	
J. Low dense or open; intermediate fuel sparse or absent — K	
K. Fine low fuel dense to open — L	
L. Fine low fuel dense — M	
M. Surface fuel present, not sparse — N	
N. Surface fuel fine and/or small (13) (fig. 3a, c)	100
NN. Surface fuel medium and larger (14)	80
MM. Surface fuel sparse or absent (15) (fig. 3b)	65
LL. Fine low fuel open — O	
O. Surface fuel present, not sparse — P	
P. Surface fuel fine and/or small — Q	
Q. Surface fuel fluffy (16)	100
QQ. Surface fuel jumbled or thatched (17)	75
QQQ. Surface fuel compact (18)	50

	Rating
PP. Surface fuel medium and larger (19)	40
OO. Surface fuel sparse or absent (20)	30
KK. Fine low fuel sparse or absent — R	
R. Small low fuel dense — S	
S. Surface fuel present, not sparse — T	
T. Surface fuel fine and/or small — U	
U. Surface fuel fluffy (21)	100
UU. Surface fuel jumbled or thatched (22)	50
UUU. Surface fuel compact (23)	30
TT. Surface fuel medium or larger (24)	30
SS. Surface fuel sparse or absent (25)	20
RR. Small low fuel not dense — A	
JJ. Low fuel and fine and small intermediate fuel dense or open — V	
V. Low fuel fine and/or small — W	
W. Surface fuel present, not sparse — X	
X. Surface fuel fine and/or small (26) (fig. 3d, e)	100
XX. Surface fuel medium and larger (27)	90
WW. Surface fuel sparse or absent (28) (fig. 3f)	70
VV. Low fuel medium and larger — Y	
Y. Surface fuel present, not sparse — Z	
Z. Surface fuel fine and/or small — a	
a. Surface fuel fluffy or jumbled (29)	100
aa. Surface fuel thatched or compact (30)	80
ZZ. Surface fuel medium and larger (31)	65
YY. Surface fuel sparse or absent (32)	50
JJJ. Low fuel sparse or absent; fine and small intermediate fuel plentiful — b	
b. Ladder fuels present — c	
c. Fine and/or small surface fuels present, not sparse — d	
d. Surface fuel fluffy or jumbled (33)	100
dd. Surface fuel thatched or compact (34) (fig. 4a)	80
cc. Fine and/or small surface fuel sparse or absent — e	
e. Medium and larger surface fuels jumbled (35)	60
ee. Medium and larger surface fuels not jumbled (36)	40
bb. Ladder fuels absent — A	

Interpretation of Ratings

Horizontal continuity must be considered in evaluating natural fuel beds as to rate of spread. The terms defined earlier can be used to interpret, or correct, mean ratings obtained from sample plots. Such interpretation is especially important where patches of high-hazard fuels are interspersed with low-hazard patches or blanks larger than a sample plot. Until research defines significant levels of continuity and measures their effects, the following rules of thumb (not yet field tested) are suggested for calculating area means:

Continuous. — Use mean of highest rated 50 percent of fuel-occupied plots, disregarding blanks.

Mixed. — Use mean of highest rated 75 percent of occupied plots, disregarding blanks.

Interspersed. — Use mean of all occupied plots, disregarding blanks.

Broken. — Use mean of all plots, including blanks.

Interrupted. — Use one-half the combined means of fuel beds separated by breaks.

The 100-point scale implies a degree of accuracy in rating fuels that does not now exist. The old regional fuel classification schemes defined five rate-of-spread classes at most; ability to discriminate and evaluate many more has not been proven. However, the ultimate goal is to be able to estimate actual rate of spread, which can exceed 100 chains of perimeter an hour. Therefore, retention of the 100-point relative scale appears logical. Differences smaller than five points in the present ratings, and perhaps some larger ones, cannot be considered significant. However, they are thought to be in the right direction, and research may show that they are real.

The ratings represent relative potential rates of spread, which would be used in fire control planning. These are most reliable under severe burning conditions. Knowledge of present and past weather must be used to interpret ratings for current use, as in scouting a fire. Fuels clearly dominated by fine, dead, well-aerated components have high ratings, but they burn slowly or not at all during periods of high humidity or after even light rain, regardless of buildup. On the other hand, types largely made up of coarse fuels have much lower ratings but continue to support fire spread under temporarily damp conditions if buildup is high. And types with high ratings whose major component is living vegetation commonly require both high buildup and dry current conditions to burn at all. Thus there is no such thing as a static, self-sufficient fuel rating.

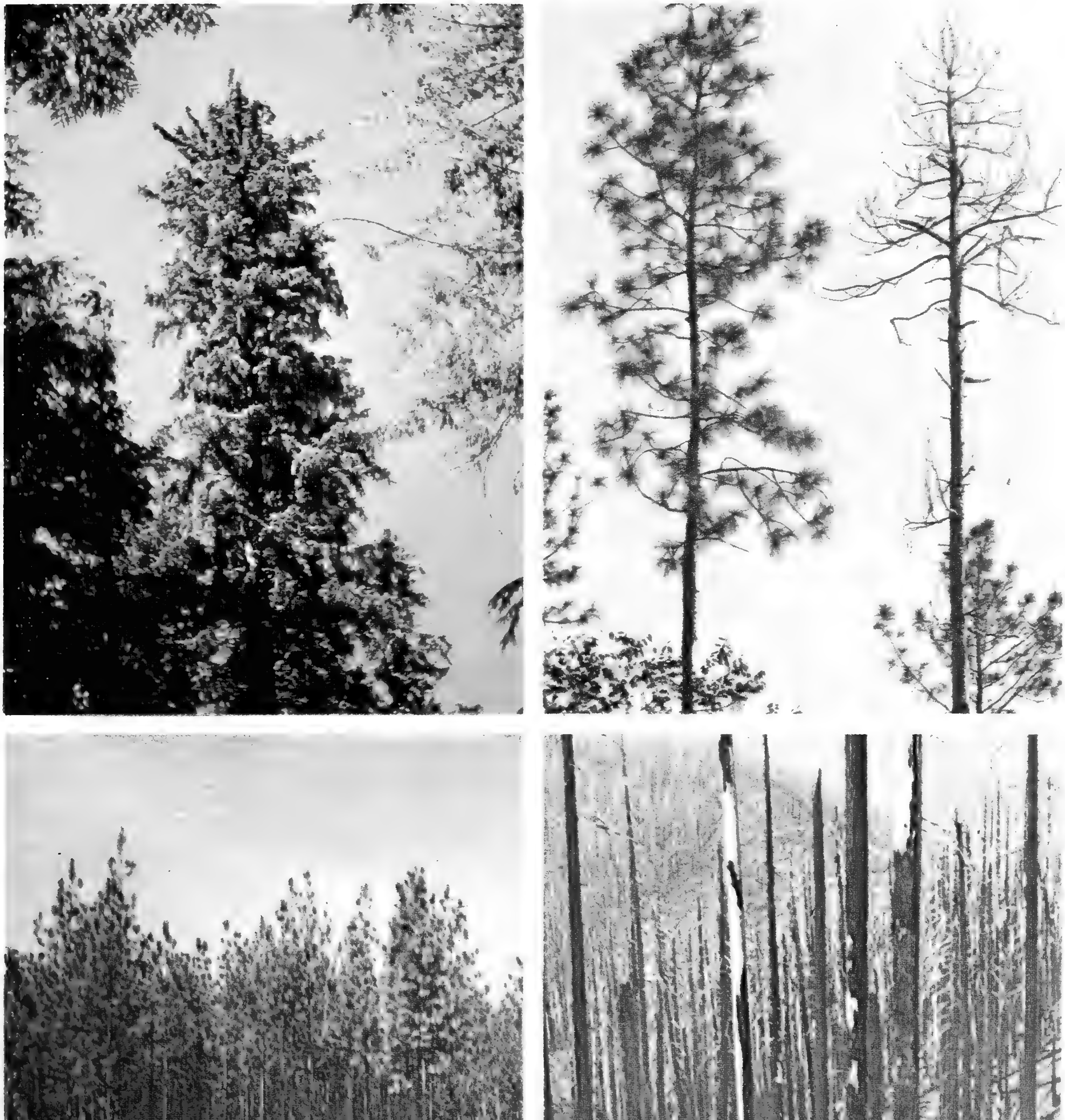
Crowning Key

Key No. 2 identifies fuel characteristics that lead to crown fires in the canopy and subcanopy,[9] according to the accepted definition of crowning, i.e., "Fire advancing from crown to crown . . ." (USDA Forest Service 1956).[10] The key ranks crowning potential by increasing numbers from 0 to 10. The rankings are based on observations and deductions by the author and are purely ordinal. No technique is available for calculating the mathematical probability that a fire will crown under given conditions.

The crowning key covers fire propagation both by progression of a flame front and by mass transport of firebrands (spotting). Both types of propagation operate when fine aerial fuels are abundant. Mass transport becomes increasingly important as amount and continuity of aerial fuels decline, and it is the only aerial mechanism of spread when crowns are dead, leafless, and noncontiguous. Wind or upslope is necessary for continuous spread through the crowns to occur. Factors conducive to rapid spread and high intensity of fire in lower fuels — e.g., drought, large accumulations of fuel — also abet crowning but are not prerequisite to it. Therefore, the key is based only on essential attributes of the crowns themselves (fig. 5); the user must consider the other factors to estimate whether crowning is likely to occur in any given situation.

[9] *Fires are also commonly said to "crown" through brush of no great height; the rate-of-spread key implicitly covers this type of spread.*

[10] *"Crowning-outs," "torch-outs," or "flareups" of individual trees or clumps do not qualify as crowning under this definition. These phenomena contribute significantly to rate of fire spread and difficulty of control by scattering many embers but do not, of themselves, constitute spread through the crowns.*



a. b. c. d.

Figure 5. — Crown fuels.

a. Dense live crown — Engelmann spruce (*Picea engelmannii* Parry), Idaho
b. Open live crown — longleaf pine, Louisiana
c. Dead crowns — slash pine (*Pinus elliottii* Engelm.), Mississippi
d. Snags spaced closer than 33 feet — Douglas-fir, Oregon

Key No. 2: Crowning Potential

	Rating
A. Foliage present, trees living or dead — B	
B. Foliage living — C	
C. Leaves deciduous or, if evergreen, usually soft, pliant, and moist; never oily, waxy, or resinous (1)	[a]0
CC. Leaves evergreen, not as above — D	
D. Foliage resinous, waxy, or oily — E	
E. Crowns dense — F	
F. Ladder fuels plentiful — G	
G. Canopy closure >75 percent (2)	9
GG. Canopy closure less (3)	7
FF. Ladder fuels sparse or absent — H	
H. Canopy closure >75 percent (4)	7
HH. Canopy closure less (5)	5
EE. Crowns open — I	
I. Ladder fuel plentiful (6)	4
II. Ladder fuels sparse or absent (7)	2
DD. Foliage not resinous, waxy, or oily — J	
J. Crowns dense — K	
K. Ladder fuels plentiful — L	
L. Canopy closure >75 percent (8)	7
LL. Canopy closure less (9)	4
KK. Ladder fuels sparse or absent — M	
M. Canopy closure >75 percent (10)	5
MM. Canopy closure less (11)	3
JJ. Crowns open — N	
N. Ladder fuels plentiful (12)	3
NN. Ladder fuels sparse or absent (13)	1
BB. Foliage dead — O	
O. Crowns dense — P	
P. Ladder fuels plentiful — Q	
Q. Canopy closure >75 percent (14)	10
QQ. Canopy closure less (15)	9
PP. Ladder fuels sparse or absent — R	

[a] *Rare instances have been reported, resulting from extreme drought.*

	Rating
R. Canopy closure >75 percent (16)	8
RR. Canopy closure less (17)	4
OO. Crowns open — S	
S. Ladder fuels plentiful (18)	6
SS. Ladder fuels sparse or absent (19)	2
AA. Foliage absent, trees dead — T	
T. Average distance between trees 33 feet or less — U	
U. Ladder fuels plentiful — V	
V. Trees with shaggy bark and/or abundant tinder (20)	10
VV. Trees not as above (21)	8
UU. Ladder fuels sparse or absent — W	
W. Trees with shaggy bark and/or abundant tinder (22)	10
WW. Trees not as above (23)	5
TT. Average distance between trees >33 feet (24)	2

Field Test of Keys

Preliminary versions of the keys were field tested in Florida, North Carolina, Minnesota, Montana, California, and Washington to assay their usefulness and the reactions of potential users. Tests in the first five locations included comparisons of ratings of the same points by two or more people. Duplicate tests were not made in California and Washington where experienced fire research personnel concentrated on comparing the key ratings with their experience in regional fuel types. Both the objective and subjective results of testing pertain to the rate-of-spread key almost exclusively because crowning potential was negligible on most of the test areas.

Consistency of Determinations

Fewer actual field determinations were made than had been hoped for, and they were made in diverse ways. Nevertheless, consistency among users of the key was remarkably good, as measured by comparison of type numbers arrived at and of mean ratings for areas.

Eight men with diverse backgrounds at the Northern Forest Fire Laboratory tested the rate-of-spread key in a mixed conifer stand (mainly Douglas-fir, western larch (*Larix occidentalis* Nutt.), and Engelmann spruce) near Missoula, Mont. Emphasis was mainly on analyzing the construction and operation of the key, but members of the group did rate the same seven points independently. Agreement on type number readout ranged from two of seven[11] to six of eight. However, all four experienced fire researchers agreed on two types, and three of the four on two others;

[11] *Three individual ratings were omitted, one by each of three testers.*

the spread was only 8 points, 49 to 57. The extreme range of mean ratings was from 40 for a forestry student to 76 for a visiting engineering professor.

Personnel of the Southern Forest Fire Laboratory rated 12 points in Florida and 13 in North Carolina, usually only one point in a type. In Florida all three men agreed on four types and two of three on four more. Averaging of ratings has little meaning under the circumstances, but, for what it is worth, the spread from high to low average was 11 points (78 to 67). Two of the same men made the North Carolina ratings, agreed on 11 out of 12, and had mean ratings only four points apart (71 and 67).

Two seasonal employees of the North Central Forest Experiment Station rated 12 points in an area of jack pine slash. They agreed on 10 of 12 points, and their averages were only one point apart (43 and 42).

In a test of the crowning key the two North Carolina observers agreed on all eight points that both rated. In Florida all three observers agreed on four of the six points rated, and two of three agreed on the other two points. Except at these points, fuels above the intermediate stratum were either lacking or so sparse that crowning potential was not considered worth rating.

Accuracy of Ratings

Fuel ratings made with the preliminary rate-of-spread key did not accord particularly well with regional fuel-type standards. The most important discrepancy resulted from failure to recognize the rapid spread in grass, which is in the highest rate-of-spread type in every region of the country. The revised key put grass in about its proper relative position by adding the "fluffy" compactness class. At the opposite extreme, the key gave high ratings to all southern brush types because green foliage and twigs were counted as fuel. Some of these types on the wettest sites seldom burn, hence are "Low" in the regional scale. However, all can burn fast and hot after sufficient drought. Mature pine timber in California was overrated because (1) "thatched" litter was interpreted as "jumbled" at one point, and (2) the other point was in the worst combination of surface and low fuels on the area. These test results emphasize that knowledge of the readiness of green vegetation to burn is prerequisite to use of the keys, that definitions must be clearly understood, and that a fuel evaluation by any means at a single point is not adequate to characterize an area.

Actually, close agreement with regional ratings would not necessarily be a point in favor of the key. As stated earlier, the old ratings include allowances for slope steepness, topographic exposure to weather, and effects of stand characteristics on microclimate, whereas the key attempts to deal strictly with properties of the fuels themselves. Also the absolute and relative values of ratings vary strikingly among regions. Comparison of northern Rocky Mountain with Pacific Northwest fuel types gives an example of interregional disparity of ratings for fuels that are similar appearing. The absolute ratings for the northern Rocky Mountains in chains-per-hour are Low-3.5, Medium-6.0, High-13.0, Extreme-20.0; on a 100-point relative scale these would become 17.5, 30, 65, and 100. Reduced to a 100-point scale, the corresponding Pacific Northwest values would be 1, 4, 20, and 100. In another comparison, rate of spread in southeastern fuels generally is much higher for a given descriptive word rating than in western fuels. The predominance of fine, well-aerated fuels in open forest stands in the South is responsible.

Several pointed out that inability to account for continuity prejudiced the ratings of areas even though individual points were rated accurately. Thus, mean slash ratings, especially for jack pine, appeared low; and the range in point ratings showed why — bodies of extreme-spread fuels alternated with areas that could be completely devoid of fuel. Fire, especially when wind driven, readily jumps considerable gaps in otherwise high-rated fuels, but knowledge is not available to evaluate discontinuities. This criticism led to the suggestion that continuity be used in deriving mean ratings.

There was no basis for evaluating the accuracy of the key to crowning potential, since this factor is not rated separately by existing fuel-type systems and has never been measured objectively.

User Reaction

All who tested the keys reacted favorably to the concept involved, and they raised surprisingly few questions concerning the ratings. However, all made suggestions for improvement, and most raised questions about the validity and adequacy of various aspects of construction and use. Even after revisions, there are still areas of continuing dissatisfaction:

1. *Terminology and definitions.* — The suggested terminology is not fully satisfactory, as a full complement of terms and precise definitions must evolve over time. The most serious flaw is the absence of terms by which to define loading with some precision as a discrete variable. Unfortunately, simple criteria of loading that can be applied universally are not available. There also is no provision for recognizing chemical differences; perhaps local adaptations of the keys can fill the need temporarily by "plugging in" species and physiological condition — e.g., stage of development — when their effects on flammability are known.

2. *Number of fuel combinations to be rated.* — One reviewer felt the rate-of-spread key should cover all possible combinations of fuel characteristics; others advocated reducing the number of combinations by merging or eliminating some with nearly equal ratings. The principle finally followed was to provide a basis for (1) distinguishing between fuels that look somewhat alike but burn quite differently and (2) showing that some fuels that superficially look quite different result in essentially the same fire behavior.

3. *Confidence in identifying and rating fuel types.* — Everybody testing the keys felt some uncertainty about the path he followed through them and the accuracy of the readouts at which he arrived. Some uncertainty in the use of fuel keys, which are a new development, should not dismay anybody who has taken his lumps in using the much more precise taxonomic keys that are accepted as valuable tools for identifying plants, animals, rocks, etc. Identification of fuel types cannot be precise because the criteria and supporting terms are not defined precisely. Therefore, the path through the key depends partly on the judgment of the person using it. Deciding between criteria of compactness is particularly vexing; "thatched" grades into "jumbled," "dense" into "open," and so on. Consequently, one is seldom sure he has followed the "right" path and arrived at the best characterization of the fuel; in fact, men experienced in rating fuels frequently can tell that they have obtained an inaccurate rating and should start over. (Possibly too much knowledge biases judgment, especially when it becomes obvious that the key is going to rate a point much higher or lower than the obvious general level for an area.) However, the same problem would exist if the criteria were precise measurements. The characteristics of fuel are continuous variables, mostly within wide ranges, and their effects on fire behavior are also continuous. Therefore, breaks in the continuous scale, which are necessary for operational use, come at arbitrary points whose appropriateness is subject to question.

Actually, the fuel keys have two safeguards that taxonomic keys lack: (1) several different paths can lead to essentially the same ratings, so that a single "wrong" turn does not necessarily invalidate final readout; and (2) inaccuracies in single ratings should tend to average out when areas are sampled at a number of points.

Uses of Fuel Keys

Fuel keys constitute a recognition scheme, not a fuel appraisal system. However, the keys proposed here embody the same principles of fuel measurement that the ultimate appraisal system is expected to use.[12] The main differences are (1) the keys use descriptive terms where the ultimate system will have measurements, and (2) ratings given by the keys are relative and tentative, based on preliminary calculations, where the ultimate system will have estimates of absolute figures established through theory and experimentation. Therefore, the keys can be used as a partial preliminary version of the fuel appraisal system and, being compatible in form and output, as an adjunct of the ultimate system for certain purposes.

Training

Fuel keys may be of greatest value as training aids because they establish a disciplined, objective approach to fuel appraisal. The user progresses by a series of simple decisions to recognition and evaluation of highly complex fuel bodies. Standardized terminology, relevant only to fuel evaluation, is used in logical sequence. Equally important, concepts and information not required for physical description and evaluation of the fuels themselves are not introduced, however important they may be for determining fire behavior, e.g., the direct and indirect effects of topography. Thus, after learning only a few basic "building blocks" and the scheme of fitting them together, the beginner is equipped to recognize significant combinations of fuel characteristics anywhere. By contrast, existing fuel "classification" systems rely on memorizing intraregional fuel types on the basis of general appearance, and knowledge of the fuels of one region is seldom fully applicable in another.

Limited instructional experience incidental to testing suggests that people learn to use the keys readily. If anything, those with the least prior knowledge of fuel evaluation learn most rapidly, apparently because they (1) are devoid of prejudice and (2) do not have enough knowledge to try and extend the keys beyond their intended scope. Users quickly learn the early stages of a key so that they make rather complicated determinations by means of only two or three terminal steps and may not need the key at all for recurrent simple determinations. One critic's comment, that "we come to a degree of simplicity that borders on ridiculous," may be the ultimate recommendation of the fuel key as a training medium.

Inventory

The results of field testing suggest that fuel keys can be used to make consistent, reasonably accurate fuel inventories. Average fuel ratings for accepted vegetative types can be obtained from only a few observations; 10 appear adequate in rather uniform fuels, but more would be necessary where the range of possible individual ratings is great, as in logging slash. One milacre appears to be about the optimum size for rate-of-spread plots. Larger plots vary so much internally that it is difficult to select the representative condition;

[12] *Preliminary report of Forest Fuels Work Conference of March 3-7, 1969, on file in USDA Forest Service Division of Fire and Atmospheric Science Research, Washington, D.C.*

smaller ones exaggerate interplot variation so that number of observations needed to give a reliable average becomes excessive. Variation between plot ratings, and especially the frequency and location of very low ratings, will provide an estimate of fuel-bed continuity, for what it may be worth.

Crowning potential can best be rated at points rather than on plots of a specified size. The rating depends on ability of fire to climb into the crowns, which may require ladder fuels on only one tree, and ability to spread through the crowns, which is a function of crown characteristics over considerable area.

Fire Reconnaissance

Acquisition of detailed fuel information for use in controlling wildfires is a specialized form of fuel inventory that puts a premium on speed and recognition of features that significantly influence strategy and tactics. Line scouts and other overhead on large fires commonly are a heterogeneous lot in terms of experience and basic knowledge; extraregional overhead may never have seen the fuels they must contend with. Fuel keys can provide a common basis for understanding that will prevent serious errors in judgment. Some preliminary coordination is necessary, mainly to get general understanding of what elements of green vegetation will burn under existing and expected weather conditions.

Interfunctional Understanding of Fuels

If they prove to be as good a training medium as expected, the keys can be used to bring much-needed understanding of fuels by people engaged in all phases of forest land management and use. Resource managers continually manipulate vegetation, thereby changing fuel characteristics and often strongly influencing the ability to protect the forest (or other wild land) from fire. The change may require corrective action that becomes a big, unexpected cost item to the operation, as when precommercial thinning slash must be abated. Failure to anticipate the necessary action occurs largely because resource managers tend to be unaware of the consequences of their fuel-modification activities, which also have commonly been overlooked by research in the resource management fields. Few people outside the fire control function have ever learned to understand existing fuel classification schemes.[13] The ratings (H-H, M-L, etc.) are incomprehensible to them, and they hesitate to accept so subjective a method for making evaluations. The fuel keys can provide the common basis of understanding, with a familiar, reasonably objective rationale.

Interregional Coordination

The keys can serve temporarily as a common base for comparing regional fuel types until a national fuel appraisal system is developed. Key ratings of typical fuels in the field, or even from standard photographs, would establish the place of each regional type in the national scale. It would be equally possible to apply the keys to areas where fuels are described in locally familiar terms, e.g., where the relation of fire behavior to forest type is well known and no separate fuel evaluation system exists (Van Wagner 1965). The coordination, although perhaps crude, would give a national agency like the Forest Service its first opportunity to compare the fuel component of the fire problem among regions as a partial basis for equitable allocation of protection effort.

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[13] *Rather surprisingly, the regional fuel classification schemes have rarely been made generally available through formal publication. Distribution has been mainly within the fire control divisions of the U.S. Forest Service and other public protection agencies.*

Discussion

The principle of using keys to *identify and describe* materials is both proven and widely used; its effectiveness depends on terminology that permits clear discrimination between significant conditions or levels of the same conditions in the material. Such terminology for forest fire fuels has not existed heretofore. Therefore, an important contribution of this paper is the proposal and definition of terms that can be used universally to describe fuel characteristics.

Only two keys are presented — the intent being mainly to illustrate the principle rather than to suggest that here is a descriptive system for fuels, all ready for use. Even the crudely calculated rate-of-spread values used here suggest that some distinctions made in the key are insignificant and that some significant distinctions may have been omitted. Nevertheless, the keys do identify fuels in terms of conditions that are recognizable in the field and essentially independent of specialized technical knowledge. Therefore, as research provides increasingly accurate quantitative definitions of terms, clearer distinctions can be made and the keys can become logical frameworks for displaying fuel data and calculating the effects of fuels on forest fire phenomena. Additional keys can be developed as needed, relating to, say, ignition probability, fire intensity, and resistance to control; or, conceivably, increased knowledge may permit eventual consolidation of all information into one master key that will serve all purposes.

The key approach to fuel description is straightforward and simple in concept, but it further emphasizes that full description of even a rather simple fuel involves cognizance and interrelation of much detailed information. This fact helps to explain why use of fuel information in forest fire control has lagged and accounts for the constant earnest plea by protectionists that fuel appraisal systems be kept simple.

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Supplemental Set of Keys for Field Use

KEY NO. 1: RATE OF SPREAD

	Rating
A. Fuel essentially confined to surface layer — B	
B. Fine fuel present, not sparse — C	
C. Fine fuel fluffy (1) (fig. 1a, b)	100
CC. Fine fuel jumbled (2) (fig. 1b, c)	18
CCC. Fine fuel thatched — D	
D. Small fuel jumbled (3)	10
DD. Small fuel, if present, not jumbled (4) (fig. 1d)	5
CCCC. Fine fuel compact — E	
E. Small fuel jumbled (5) (fig. 2a)	5
EE. Small fuel thatched (6)	3
EEE. Small fuel sparse or absent — F	
F. Medium fuel jumbled (7) (fig. 2b)	3
FF. Medium fuel not jumbled (8) (fig. 1e)	1
BB. Fine fuel sparse or absent — G	
G. Small fuel jumbled or thatched (9)	3
GG. Small fuel sparse or absent — H	
H. Medium fuel jumbled (10)	2
HH. Medium fuel not jumbled — I	
I. Larger fuel jumbled (11)	1
II. Larger fuel not jumbled (12)	<1
AA. Fuel available in low and/or intermediate layers — J	
J. Low dense or open; intermediate fuel sparse or absent — K	
K. Fine low fuel dense to open — L	
L. Fine low fuel dense — M	
M. Surface fuel present, not sparse — N	
N. Surface fuel fine and/or small (13) (fig. 3a, c)	100
NN. Surface fuel medium and larger (14)	80
MM. Surface fuel sparse or absent (15) (fig. 3b)	65
LL. Fine low fuel open — O	
O. Surface fuel present, not sparse — P	
P. Surface fuel fine and/or small — Q	
Q. Surface fuel fluffy (16)	100
QQ. Surface fuel jumbled or thatched (17)	75
QQQ. Surface fuel compact (18)	50
PP. Surface fuel medium and larger (19)	40
OO. Surface fuel sparse or absent (20)	30
KK. Fine low fuel sparse or absent — R	
R. Small low fuel dense — S	
S. Surface fuel present, not sparse — T	
T. Surface fuel fine and/or small — U	
U. Surface fuel fluffy (21)	100
UU. Surface fuel jumbled or thatched (22)	50
UUU. Surface fuel compact (23)	30
TT. Surface fuel medium or larger (24)	30
SS. Surface fuel sparse or absent (25)	20
RR. Small low fuel not dense — A	
JJ. Low fuel and fine and small intermediate fuel dense or open — V	
V. Low fuel fine and/or small — W	
W. Surface fuel present, not sparse — X	
X. Surface fuel fine and/or small (26) (fig. 3d, e)	100
XX. Surface fuel medium and larger (27)	90
WW. Surface fuel sparse or absent (28) (fig. 3f)	70
VV. Low fuel medium and larger — Y	
Y. Surface fuel present, not sparse — Z	
Z. Surface fuel fine and/or small — a	
a. Surface fuel fluffy or jumbled (29)	100
aa. Surface fuel thatched or compact (30)	80
ZZ. Surface fuel medium and larger (31)	65
YY. Surface fuel sparse or absent (32)	50
JJJ. Low fuel sparse or absent; fine and small intermediate fuel plentiful — b	
b. Ladder fuels present — c	
c. Fine and/or small surface fuels present, not sparse — d	
d. Surface fuel fluffy or jumbled (33)	100
dd. Surface fuel thatched or compact (34) (fig. 4a)	80
cc. Fine and/or small surface fuel sparse or absent — e	
e. Medium and larger surface fuels jumbled (35)	60
ee. Medium and larger surface fuels not jumbled (36)	40
bb. Ladder fuels absent — A	

KEY NO. 2: CROWNING POTENTIAL

	Rating
A. Foliage present, trees living or dead — B	
B. Foliage living — C	
C. Leaves deciduous or, if evergreen, usually soft, pliant, and moist; never oily, waxy, or resinous (1)	[a]0
CC. Leaves evergreen, not as above — D	
D. Foliage resinous, waxy, or oily — E	
E. Crowns dense — F	
F. Ladder fuels plentiful — G	
G. Canopy closure >75 percent (2)	9
GG. Canopy closure less (3)	7
FF. Ladder fuels sparse or absent — H	
H. Canopy closure >75 percent (4)	7
HH. Canopy closure less (5)	5
EE. Crowns open — I	
I. Ladder fuel plentiful (6)	4
II. Ladder fuels sparse or absent (7)	2
DD. Foliage not resinous, waxy, or oily — J	
J. Crowns dense — K	
K. Ladder fuels plentiful — L	
L. Canopy closure >75 percent (8)	7
LL. Canopy closure less (9)	4
KK. Ladder fuels sparse or absent — M	
M. Canopy closure >75 percent (10)	5
MM. Canopy closure less (11)	3
JJ. Crowns open — N	
N. Ladder fuels plentiful (12)	3
NN. Ladder fuels sparse or absent (13)	1
BB. Foliage dead — O	
O. Crowns dense — P	
P. Ladder fuels plentiful — Q	
Q. Canopy closure >75 percent (14)	10
QQ. Canopy closure less (15)	9
PP. Ladder fuels sparse or absent — R	
R. Canopy closure >75 percent (16)	8
RR. Canopy closure less (17)	4
OO. Crowns open — S	
S. Ladder fuels plentiful (18)	6
SS. Ladder fuels sparse or absent (19)	2
AA. Foliage absent, trees dead — T	
T. Average distance between trees 33 feet or less — U	
U. Ladder fuels plentiful — V	
V. Trees with shaggy bark and/or abundant tinder (20)	10
VV. Trees not as above (21)	8
UU. Ladder fuels sparse or absent — W	
W. Trees with shaggy bark and/or abundant tinder (22)	10
WW. Trees not as above (23)	5
TT. Average distance between trees >33 feet (24)	2

[a] *Rare instances have been reported, resulting from extreme drought.*

Fahnestock, George R.

1970. Two keys for appraising forest fire fuels. USDA Forest Serv. Res. Pap. PNW-99, 26 pp., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A glossary proposes nontechnical definitions of fuel characteristics that significantly affect forest fire behavior. One dichotomous key uses the terminology to determine the relative rate of fire spread; the other key ranks probability of crown fire occurrence. The keys in themselves are not a fuel appraisal system but as an adjunct should be helpful in training, inventory, and interdisciplinary understanding of fuels.

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Headquarters for the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is in Portland, Oregon. The Station's mission is to provide the scientific knowledge, technology, and alternatives for management, use, and protection of forest, range, and related environments for present and future generations. The area of research encompasses Alaska, Washington, and Oregon, with some projects including California, Hawaii, the Western States, or the Nation. Project headquarters are at:

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